HIL Test-bed for Autonomous Satellite Formation Flying

Martín España*, José Relloso‡, José F. Argibay‡, Damián Rosetani‡,
Andrés Laudari‡, Claus Rosito†, Ignacio S. Husain†
*CONAE, ‡INVAP, †UBA

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UN-OOSA

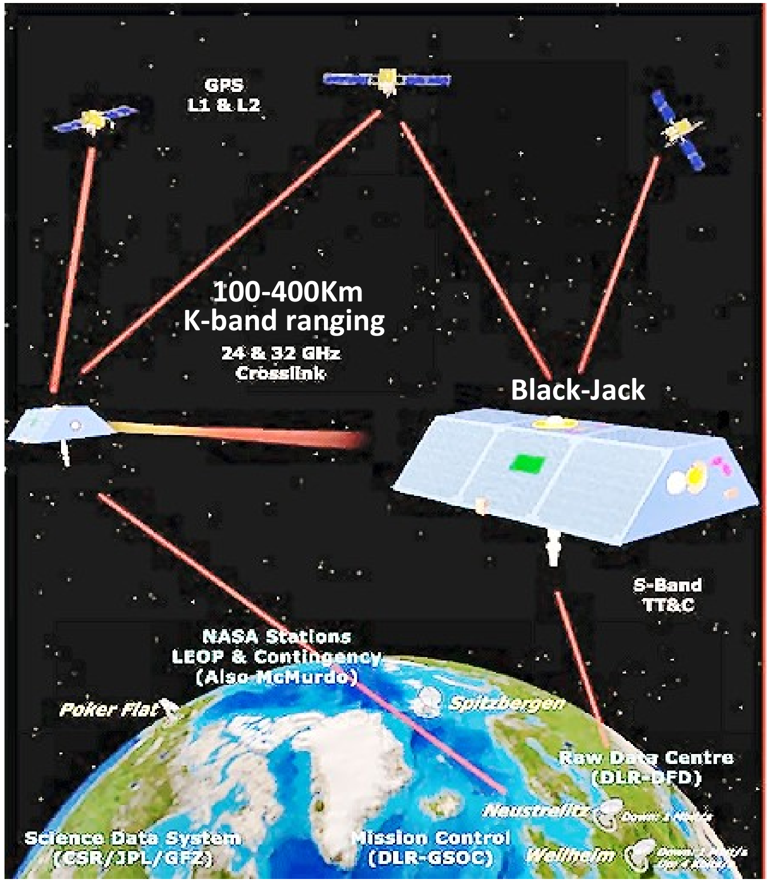
Part I: Satellite Formation Flying

- Recent alternative to traditional monolithic (often *mammouthian*) satellite architectures.
- Belongs to the larger concept of: *Distributed Cooperative Spacecraft Systems.*
- What matters in SFF is Geometry.
- Precise relative navigation and control is essential.

Why Satellite Formation Flying?

- Substitutes massive monolithic platforms.
- Deployment possible with low thrust/cost launchers.
- Introduces redundancy & flexibility reducing design risks.
- Possible in-orbit technology renewal or satellite replacement.
- Extends missions life-span without technology obsolescence.
- Enables unprecedented multipoint Earth observation perspectives.

GRACE (DLR/NASA, 2002-2017)

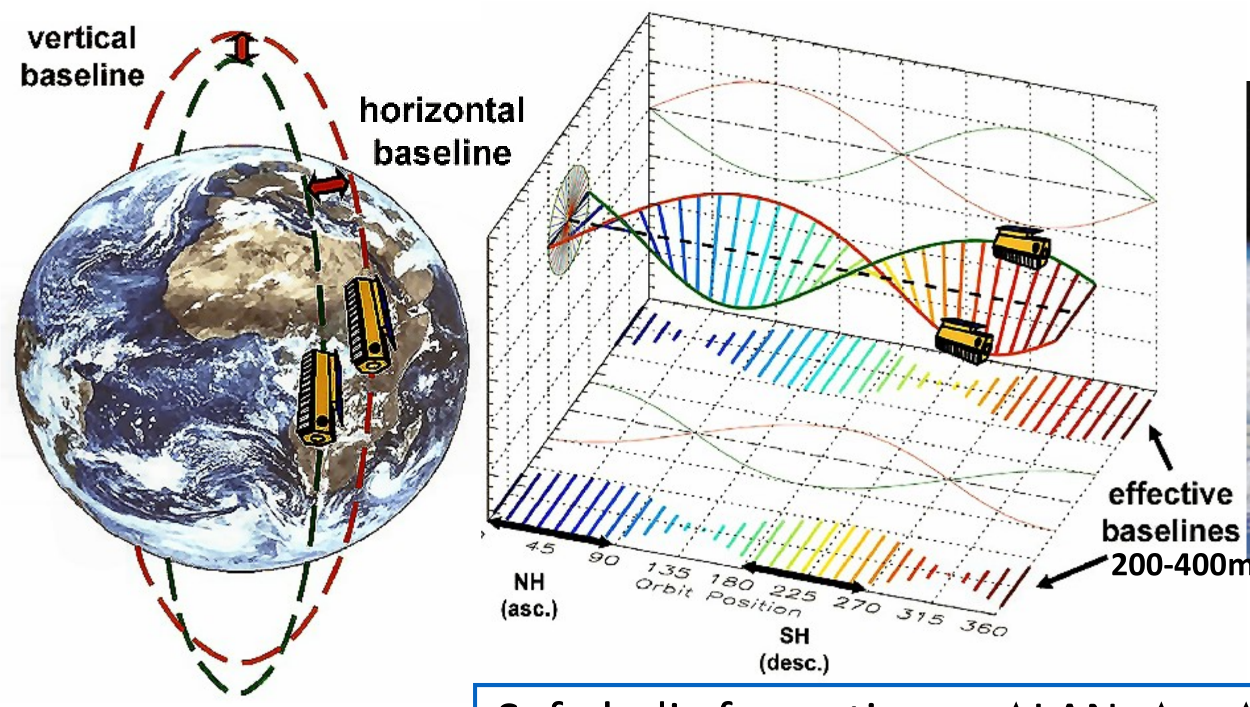


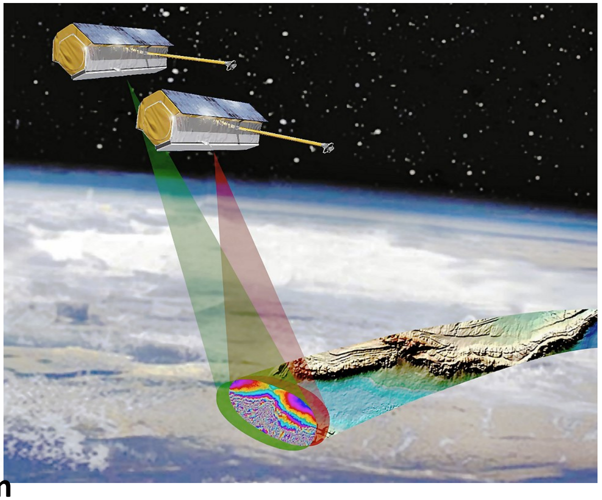
- Measures local changing gravitational field through very precise relative speed and position determination (<10µm K-band ranging)

- Applications:
  - Glaciers & sea ice.
  - Subsurface water
  - Ocean level
  - Solid Earth (earthquakes!)
  - Gravity models

TanDem-SARX (DLR, TSX-2007; TDX-2009)

- 1st Operative LEO simultaneous SAR interferometer system.
- Relative orbit control accuracy : $\leq$ 3m 1σ x-track; $\leq$ 25m 1σ a-track.
- On board relative navigation accuracy : $\leq$ 0.5m 1σ 3D.
- *Post facto* relative navigation knowledge 1σ $\leq$ 5mm 3D

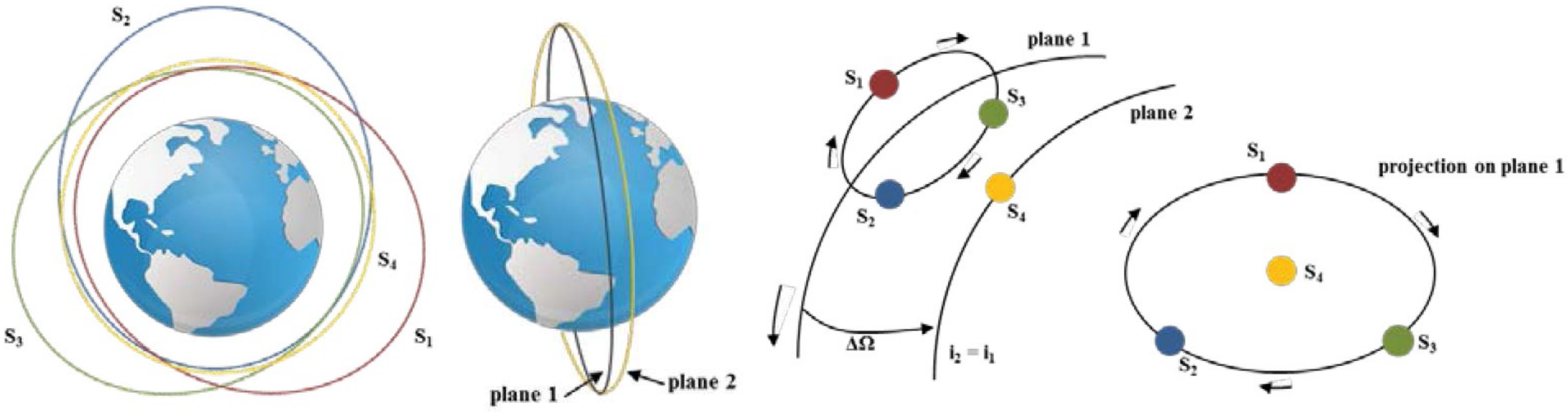




Safe helix formation $\leftarrow$ ΔLAN, Δe, $\Delta\omega$; same i & a

NetSat-Global GeomaGnetic Gradiometry (4G) (Zentrum für Telematik, GE)

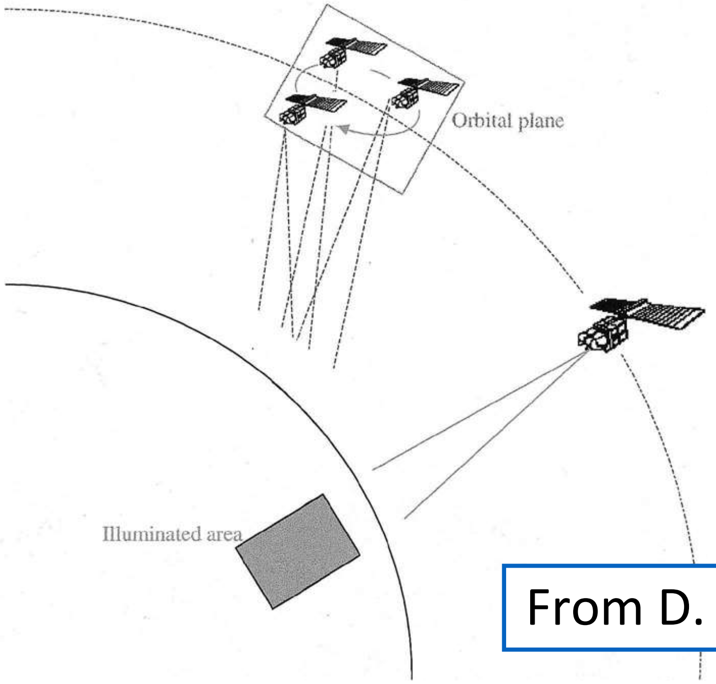
- 4-pico-satellite FF for global full geomagnetic tensor retrieval.
- In Orbit demonstrator of fully autonomous GNC w/low-thrust EP.
- Allows for E-O, N-S & Radial gradient determination.
- Tracks small-scale lithospheric magnetic field and secular variations.

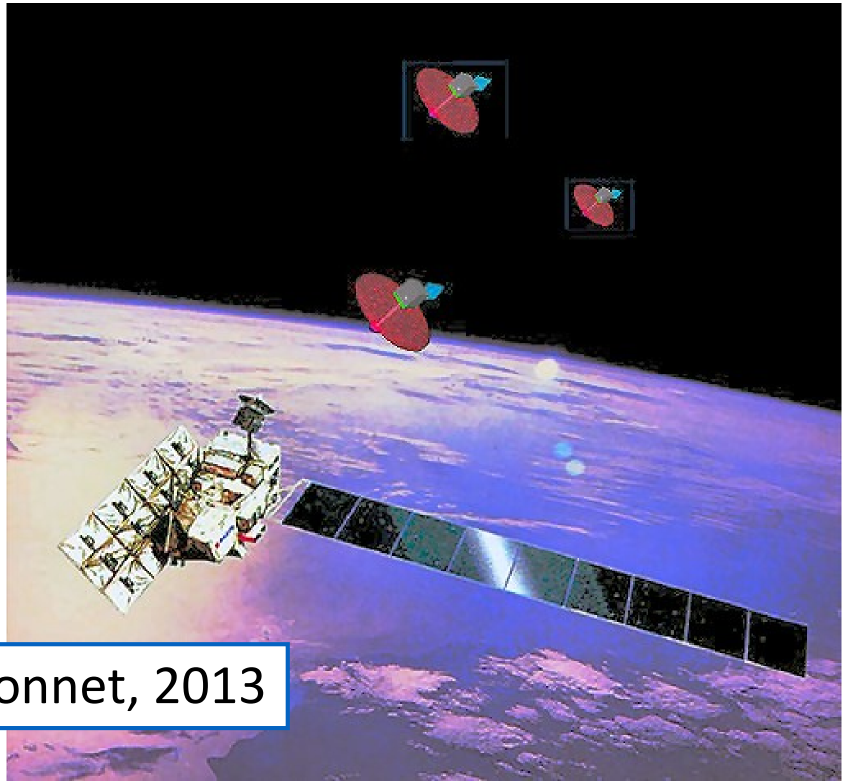


- S1, S2, S3: eccentric orbits in “Cartwheel” config. with ω´s at 120º.
- S4: same inclination with LAN offset (different plane).

Cartwheel Concept for Single-Pass Interferometric SAR (D. Masonnet, 2001)

1 SAR emitter (active)
3 SAR antennae receivers (passive)

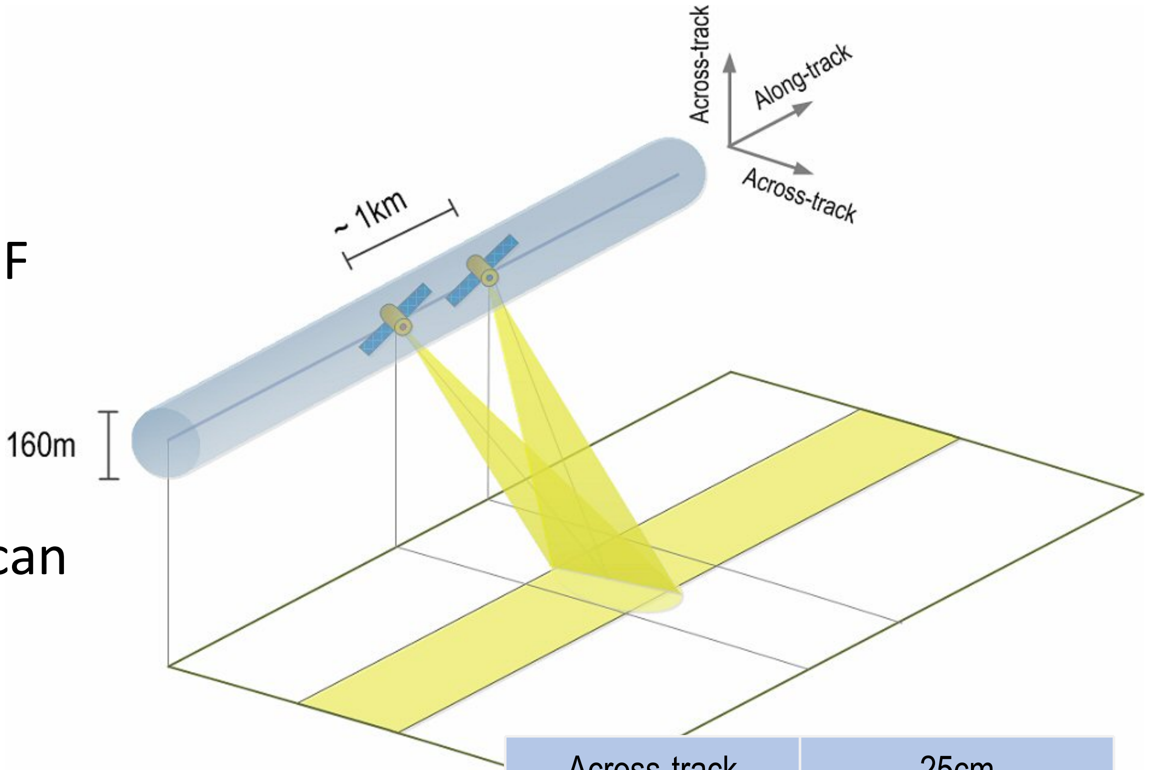




From D. Massonnet, 2013

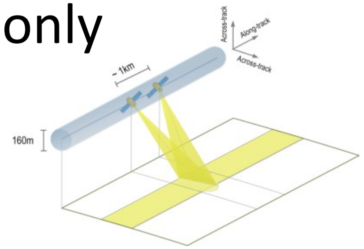
New L-Band “Double SAR” FF Mission Proposal

- Replaces a large monolithic SAR with a FF of 2 lighter, less power consuming satellites.
- Both active antennae scan the same Swath in a collaborative mode, working as one.



Across-track Nav precision	25cm - *offline* -
Along-track Nav. precision	5cm - *offline* -

New L-Band “Double SAR” FF Mission Proposal



- An innovative mission in L-Band (TanDEM-X is the only similar precedent.)
- Deployable with a lower power launcher.
- Despite performance degradation, SAR images can still be obtained with a single satellite.
- Satellite replacement is possible without aborting mission.
- Multiple secondary mission possibilities: DEM, bi-static SAR, interferometry and tomography.
- Acquisition modes may be switched among different mission's objectives.

Why Autonomous On board Navigation and Orbit Control? I

- From an operative standpoint
  - Minimizes ground orbital maintenance operations.
    - Ground tracking still used as safety back up.
  - Higher Nav & Ctrol rate (<2hs. vs 12/24hs) improves instantaneous adjustment of geometric config. to nominal.
    - Improved science data quality.
  - Whole ephemeredes is known *a-priori* by Usr. & Opr.
    - No ephemeredes updates & broadcast.
    - No data acquisition planning readjustment required.
  - More efficient RF interference and collision management.

Why Autonomous On board Navigation and Orbit Control? II

- Uniformly close to nominal flight conditions implies:
  - Minimum atmospheric friction → ↓propellant, ↑payload,

  ↑s/c useful lifespan.
  - Lower power propulsion req., enables EP with high Isp.
  - Smooth (no abrupt) maneuvers
    - reduces power on attitude control.
    - science data acquisition possible during maneuvers!
    - eases Nav filtering → persistent knowledge precision & faster more precise maneuvers.

Key Technologies & Know How´s Enabling Autonomous SFF

- High precision relative GNSS differential carier phase navigation algorithms.
- Miniaturized software-defined multi-frequency/multi-constellation GNSS receivers.
- Miniaturized star-trackers with < 10 arcsec cross-axis accuracy
- Advanced astro-dynamic modeling & non-linear control strategies to:

  a) Enforce SFF constraints, b) Min. Δv consumption

  c) Assure collision free operation.
- Small, low mass, high Isp, continuous, low-thrust EPS.

Challenges of Autonomous SFF

- Complex design and validation procedures of on-board embedded SW.
- Reliable and timely on board fault detection schemes.
- On-board integrity and safety assurance procedures.
- Intense on ground HW in the loop validation required.
- Trade off between development time and costs vs. potential operative improvements during mission.

Part II

HIL Test-bed for Autonomous Satellite Formation Flying

A CONAE/INVAP partnership under development with technical participation of the UNLP

Main Partners´ Contributions

1. CONAE:

   SPIRENT GSS8000 Multi-constellation (MC), Multi-frequency (MF) RF-GNSS signal in space simulator for Multi-receivers.

2. INVAP:

   High fidelity real time orbital propagators (ARSAT/SAOCOM)

3. UNLP:

   High Doppler MC, MF, 12 channels GNSS receivers with differential carrier phase high precision embedded algorithms

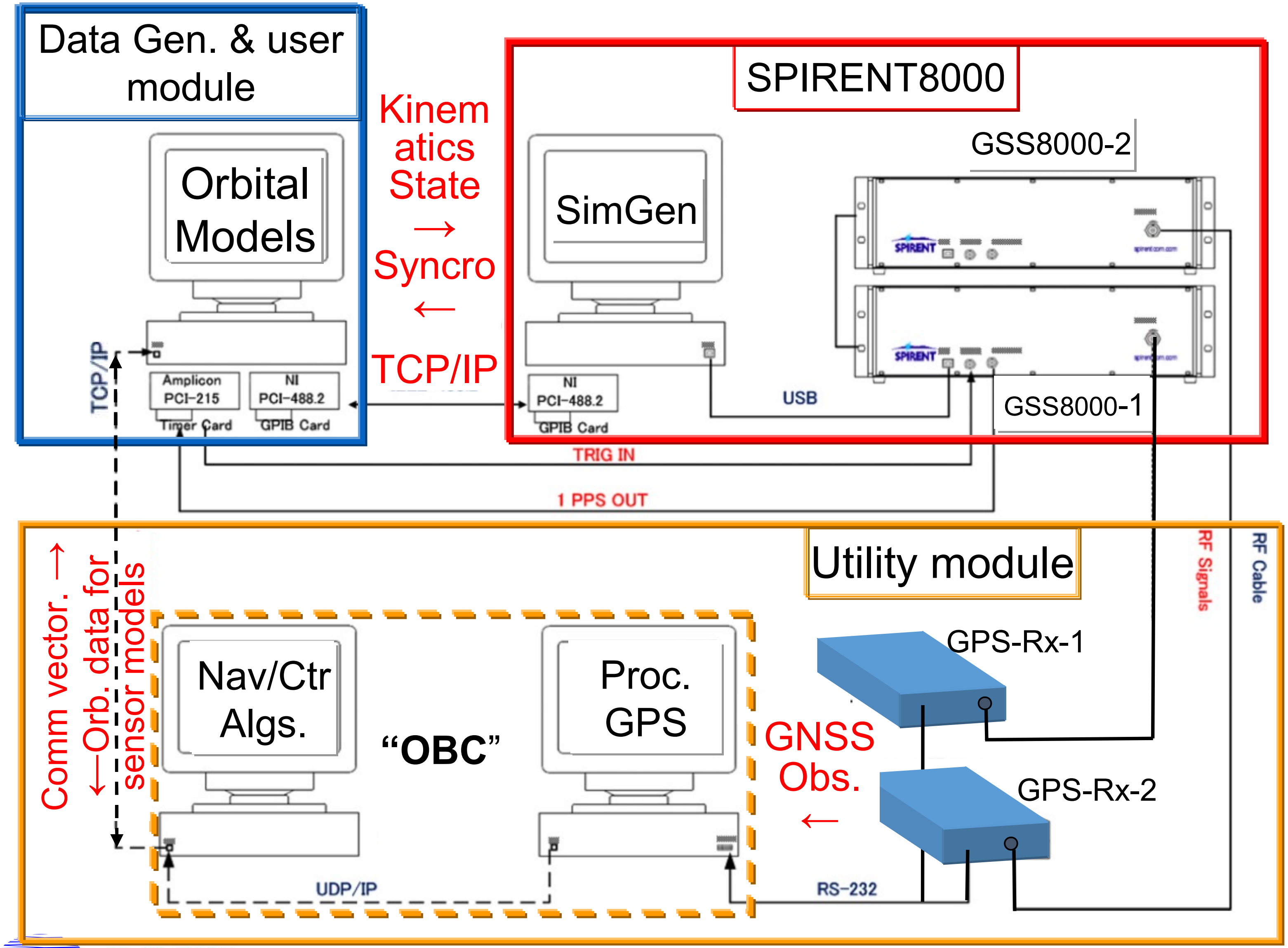
Main Requirements I

1. Shall allow to test autonomous absolute and relative orbital GNC techniques for at least 2-satellites FF relevant to EO missions.
2. Shall allow to test real time Integrated Nav. & Ctrol. algorithms embedded on an OBC flight model.
3. Absolute and relative Nav. shall be based on all available observers delivered by real physical GNSS receivers.
4. Shall have a modular structure allowing interchanging the OBC under final testing with a PC during preliminary algorithm validation.

Main Requirements II

5. Shall allow to test & validate multi-frequency/ multi-constellation GNSS SW defined orbital receivers developed by the UNLP under contract by CONAE.
6. Shall allow to validate real time, on board, differential carrier phase high precision relative navigation SW.
7. Shall allow to validate on board Precise Orbit Determination SW based on GNSS observables.

Test-Bed's General Architecture



HIL Test-bed Future Usage

- On ground concept validation of new autonomous SFF missions.
- To develop and validate new absolute and relative orbit control techniques.
- To easily compare SFF mission performances with different propulsion technologies: i.e.: Propellant vs. EP, impulsive vs. continuous, etc.
- To test and validate with HIL high precision in orbit multi-constellation multi-frequency GNSS Navigation Systems.
- To test numerical methods for relative orbit design given an observation objective (guidance problem).
- To test the impact of inter-satellite link latency.

Thank you very much for your kind attention!

Questions?

Current CONAE´s SPIRENT GSS8000 Configuration

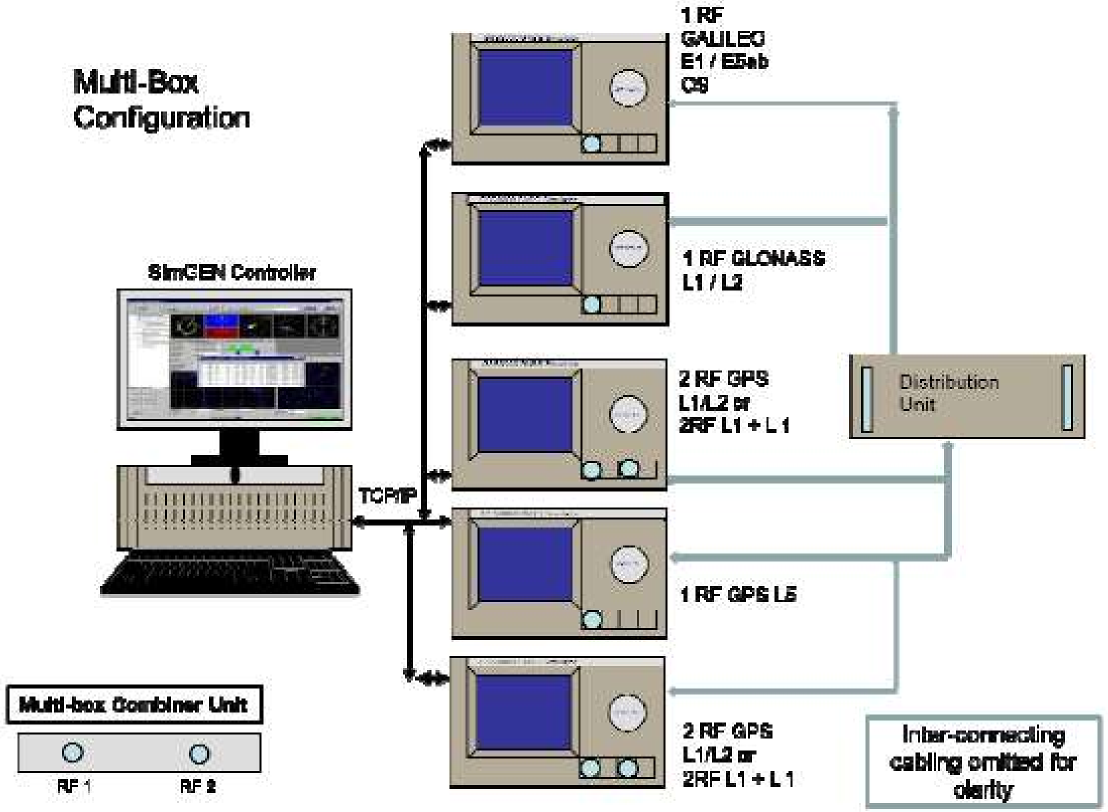
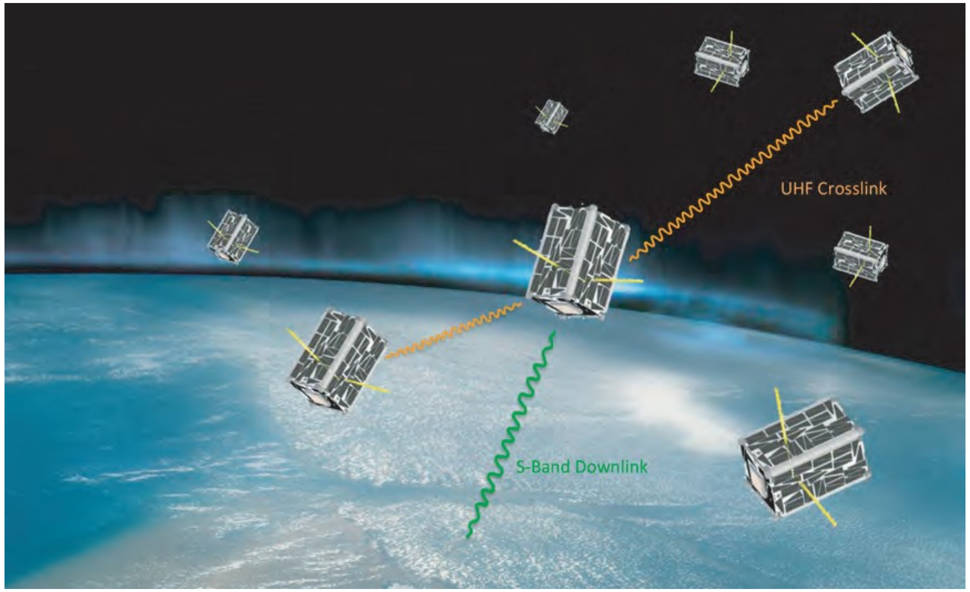
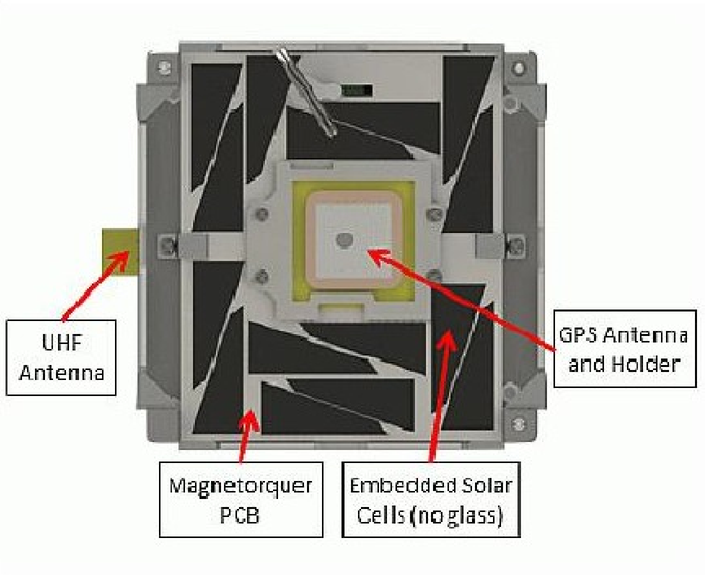


Figure 1 Functional diagram.

Edison Demonstration of SmallSat Networks (EDSN)

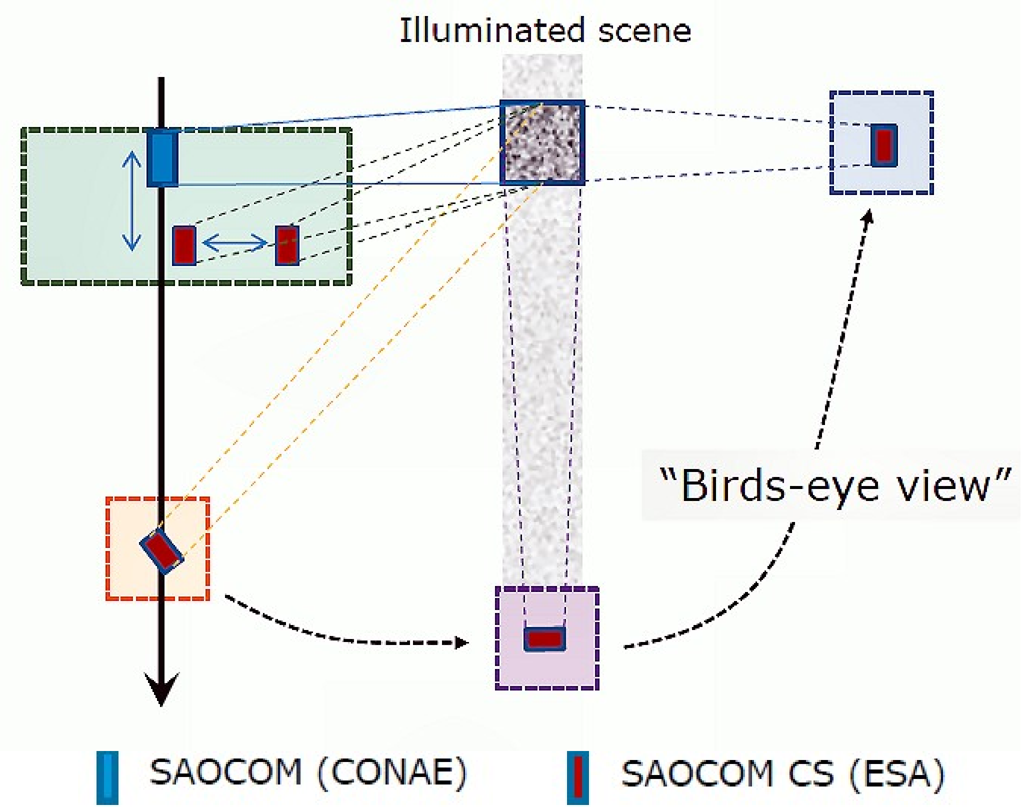
NASA´s 8 low cost (COTS) 1.5U Q-sats multi-point science data collection and transfer demonstrator.





- Operates independently of ground based systems.
- Drifts freely, no propulsion available.

SAOCOM-1B Passive Companions Proposal : A Bistatic/ Tomogr./ Interferom. SAR Mission



Tomographic phase

- ✓AT baseline < 6km
- ✓XT baseline varies ~1–6 km
- ✓Science mission driver
- ✓Duration ~2.5 years

Bistatic 1, Bistatic 2

- ✓AT baseline ≈ 250 km
- ✓Small XT baseline (phase 1)
- ✓Large XT baseline (phase 2)
- ✓Duration ~2 years

Specular phase

- ✓ **Experimental**
- ✓ **Short duration**

From: Davidson/Carnicero/Gebert/Silvestrin ESA ESTEC;2014